AD-A195 341 NBS-NRL FREE-ELECTRON LASER FACILITY FOR THE ANNUAL MFEL CONTRACTORS MEETING (3RD) HELD IN UTAH ON 16-18 MAY 1988(U) NATIONAL BUREAU OF STANDARDS GAITHERSBURG MD 18 MAY 88 1/1

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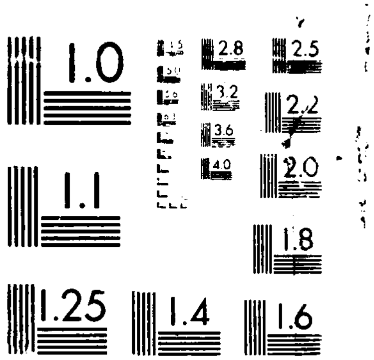

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Progress Report on the

NBS-NRL Free-Electron Laser Facility

for the

Third Annual MFEL Contractors Meeting

University of Utah

May 16-18, 1988

This work was funded by SDIO through ONR Contract No. N00014-87-F0066.

Abstract

In April, 1987, design and construction began for the NBS-NRL Free Electron Laser (FEL) Facility, which will be based on the NBS-LANL cw Racetrack Microtron (RTM) accelerator. The conceptual design of the facility is now complete, the RTM is nearing completion, and final negotiations with a wiggler contractor are underway. Progress to date is described.

A. RTM

The RTM, which is described in Reference 1, consists of a 5 MeV injector feeding a microtron. In the microtron, a pair of 180° end magnets are used to recirculate the electron beam through a 12 MeV rf linac up to 15 times for an energy gain of up to 180 MeV. The beam can be extracted from any of 14 separate return lines in 12-MeV steps. In the past year, 5 MeV injector beam tests were completed, and the beam transport line between the injector and microtron was installed. The 12 MeV linac was rf-tested at full power, and all beam transport components on the linac axis and the end magnet vacuum chambers were installed. All magnets for the return lines were designed, and beam-optical design of the transport line between the RTM and the FEL was completed. We are currently preparing to perform 17 MeV beam tests with one pass through the linac.

The results of the RTM injector beam tests are given in Reference 2. The measured, normalized transverse emittance at 5 MeV is less than 1 μm, considerably better than the 10 μm required for FEL operation at wavelengths down to 90 μm. The measured energy spread of 5 keV at 5 MeV is below the criterion of 0.4% for lasing. Furthermore, we expect the fractional energy spread to decrease with increasing beam energy.

B. RTM INJECTOR MODIFICATIONS

The RTM injector consists of a 100 keV, 5 mA dc, thermionic electron gun followed by a chopper/buncher system and a 5 MeV cw linac. The injector produces beam pulses at 2380 MHz (the rf drive frequency) with a maximum of 0.35 pC per pulse. A peak electron beam current of 2-4 A is required in the FEL to achieve lasing. For a 3.5-ps long beam pulse, this is 7-14 pC per pulse. We have proposed to increase the charge per pulse without increasing the average current in the RTM (limited by the rf power available) by reducing the beam pulse frequency to 74.375 MHz, the 32nd subharmonic of the rf frequency.

We are investigating three possible ways to achieve the required charge per pulse: subharmonic bunching, a laser-driven photoelectron gun, and subharmonic chopping. Subharmonic bunching is entirely feasible but would impress a marginally unacceptable energy variation of ± 20 keV on the beam.

A photoelectronic gun driven by a mode-locked, cw laser requires a photocathode with a 1% quantum efficiency and a one week lifetime to be acceptable for user facility operation. We are collaborating with the AT-7 group at Los Alamos to identify a suitable cathode material. Several materials have been found with more-than-adequate quantum efficiency, but their lifetimes are disappointingly short: a few hours even in high vacuum (10^{-10} Torr) at average currents that are less than 2% of what we require. Further tests at higher currents will begin soon at Los Alamos with a dc gun configuration. So far, no acceptable cathode material has been identified. Meanwhile, we have been operating a cw, mode-locked Nd:YAG laser as a prototype photocathode driver.

A very promising, recently-conceived method of increasing the peak current would involve replacing the present dc electron gun with a 100-150 mA, 110 kV, thermionic gun pulsed at 74.375 MHz. The 2 ns long gun pulses would then be chopped and bunched to the required length. The required electron gun is commercially available, the chopper would be similar to the existing one, and the existing buncher would remain intact. We are currently doing design calculations for this system. After completion of these calculations and the Los Alamos dc photocathode tests early this summer, we will decide which method to use.

C. OPTICAL CAVITY

The conceptual design of the optical cavity is complete. We have chosen a two-mirror, linear cavity with a mirror spacing of 8.062 m. This spacing gives a round trip light travel time of 53.78 ns, which, at the RTM injector frequency of 74.375 MHz, implies that there will be two electron pulses and four light pulses in the optical cavity at one time. Since the RTM is a cw accelerator and there is gain in the laser only when an electron bunch is present, the FEL behaves as a cw, harmonic-mode-locked laser. The cw nature of the accelerator results in very high average output power for the FEL.

For cavity mirrors, we plan to use multi-layer dielectric (MLD) coatings on transparent substrates. Compared to metallic coatings, the spectral bandwidth, or tuning range, is narrow. However, MLD coatings can be constructed with very high power reflection coefficients (up to R = 99.999%). Large values for R are necessary because the NBS/FEL is a low-gain laser. A second advantage is that damage thresholds for MLD coatings usually exceed those for metallic coatings. On the cavity mirrors, we expect the peak irradiance to be

1-2 GW cm^{-2}, and the average power to be 200-400 kW cm^{-2}, so that high damage thresholds are essential. A third advantage of MLD coatings is the ability to couple the light out through one mirror by using a partially transmitting/ partially reflecting MLD coating.

Diffraction losses on the cavity mirrors and the intracavity magnetic vacuum apertures will be negligible at ultraviolet and visible wavelengths and small at the infrared wavelengths for which we plan to operate. At 10 μm, the wiggler vacuum aperture diffracts 0.6%, and the dump magnet aperture diffracts 0.2%. The diffraction losses increase rapidly with increasing wavelength, and limit the lasing wavelength to $\lesssim$ 12 μm.

The wiggler will have a peak field of 0.54 T, 130 periods of 2.8 cm for UV and visible operation, and 65 periods for IR operation. Specifications for the wiggler were written in June, 1987, and a request for proposals was sent to potential wiggler contractors in August. Several proposals were received in October and were evaluated by an internal technical committee, with Dr. Brian Kincaid (AT&T Bell Laboratories) acting as an outside consultant. Negotiations with prospective vendors began in November. A signed contract is imminent.

The room where the wiggler and optical cavity will be located has been cleared of interfering equipment. We have measured ionizing radiation levels in this area during operation of the NBS neutron time-of-flight (NTOF) facility, when a 5 kW electron beam from the NBS 110 MeV linac passes through the FEL area. The measured radiation levels are in the range of 10-100 krad per year, which will give the radiation-sensitive samarium cobalt wiggler magnets an estimated useful lifetime of 5000 years. Lifetimes of optical components at this radiation level will be 1-10 years, longer than lifetimes due to opti-

cal radiation damage. We have also initiated sound and vibration measurements in the room in order to determine isolation specifications for the optical cavity.

D. USER FACILITY

The user facility will consist of two experimental rooms. The first, XA1, is an existing room adjacent to the FEL, about 1600 ft^2 in area and approximately 40 ft below ground level. It contained a beam transport line and a magnetic spectrometer connected with the NBS 110 MeV linac. We removed most of this equipment this year for conversion to the FEL facility. A building addition at ground level will contain a second experimental area, XA2, of about 2400 ft^2. In the past year we visited several laser laboratories to define experimental requirements for the new room. We also drilled a test hole for location of the optical transport system between the two experimental areas. A feasibility study is underway to determine if the site provides satisfactory support for the proposed addition. A preliminary building design was completed, and we are preparing a bid package for engineering and architectural design and construction.

E. PREDICTED PERFORMANCE

We have calculated the small-signal power gain of the NBS-NRL FEL using a three-dimensional numerical method that includes, among other things, the transverse beam emittance.[3] The small signal power gain is between 10% and 35%. In the fundamental, the small value of the gain in the UV and decreasing mirror reflectivities determine the 200 nm cutoff. However, we expect to have adequate electron beam quality to allow for operation as an oscillator on the

third harmonic down to about 150 nm. For a saturated FEL in the ideal, one-dimensional, low-gain model, the maximum power extraction efficiency from the the electron beam is 1/(2N) where N is the number of periods in the wiggler.[4] Using this model, we have estimated the optical output power for commercially available mirrors.[5] The calculated cw output power is in the range 50-200 W for 200 nm $< \lambda <$ 7 μm, and is approximately 20 W for 7 μm $< \lambda <$ 10 μm. We are performing more accurate, three-dimensional calculations.

REFERENCES

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